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Indoor Navigation with MEMS sensors

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Abstract

Accurate positioning becomes extremely important for modern application like indoor navigation and location-based services. Standalone GPS cannot meet this accuracy. In this paper a method to couple GPS and a high resolution MEMS pressure sensor is presented to improve vertical as well as horizontal (in urban canyon environment) positioning. Further, a step counter based on an accelerometer is improved with an altimeter for stair detection and automatic step length adaptation for dead reckoning inside buildings. Finally, a stand-alone system accurately tracks floor levels inside buildings, using only a pressure sensor.

Indoor Pedestrian Navigation; Location-based Services; Barometric Pressure Sensor; Step Counter; Floor Detection

1. Introduction

1.1. Motivation

Accurate navigation within buildings is advantageous for pedestrians as outdoor navigation is for drivers. In large shopping centers, they could be guided directly to shops or restaurants, without detours. New forms of location-based services, linked to GPS-equipped cell phones, could be offered for these applications. The possibilities for its use by first responders are of incalculable value: no longer would they have to search through complex corridors, instead they could be directly guided to the location where they are needed.

1.2. GPS shortcomings

Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) allow positioning and thus navigation all over the world. However, the accuracy depends on the signal quality and on how the raw measurements (the so called pseudoranges) are processed. Additional to atmospheric delays and clock errors the measurements may be distorted by the following:

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- Signal attenuation and blockage (trees, inside buildings, …): The RF engine may have problems to track weak satellite signals which results in erroneous pseudorange measurements.
- Multipath effects: delays due to reflection at building walls (especially in 'urban canyons') can cause inaccuracy since the pseudorange may be wrong by tens of meters.

Modern GPS receivers show pretty accurate performance in terms of horizontal position (latitude, longitude) whereas the altitude information is less reliable. Measurements demonstrate that especially in situation with weak signal conditions the provided altitude varies slowly over more than 40m (Figure 1). Clearly, a more reliable altitude is needed for pedestrian navigation to detect floor levels inside a building.

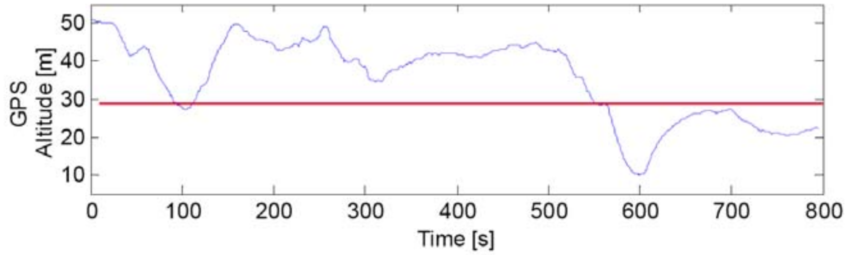

Fig. 1: Indoor altitude error measured using GPS at fixed position in an office building (2nd floor of 2 storey office building, true altitude 30m). The deviations from the actual value are substantial.

1.3. Pressure sensor as altimeter

Fig. 2: BMP085 pressure sensor in an LCC-8 housing, size 5*5*1.2mm^3, with digital output and a resolution of ±0.03hPa (RMS), corresponding to ±0.25m at sea level. The measuring range of 300 to 1100hPa covers -500m to +9000m above sea level. In ultra-low-power mode it requires 3µA at one sample / sec., stand-by mode consumption is 0.1µA. The minimum supply voltage is 1.8V.

Ambient pressure decreases with altitude. Therefore, a pressure sensor can be used to calculate the altitude using the barometric formula (1) whereas p denotes the ambient pressure measured by the sensor and p_0 the pressure at sea level.

$$altitude = 44330 \cdot \left(1 - \left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right) \text{ meters} \tag{1}$$

Normally, the pressure at sea level, which is weather dependent, must be known to obtain the correct altitude. For the Stair Detection and the Floor Finder however, only the height difference is needed.

2. GPS and pressure sensor coupling

There are several approaches to couple GPS with other sensors. When doing high level data fusion (e.g. based on the NMEA protocol) one has to face the fact that this data is highly processed and filtered by the GPS chipset. A more complex method is tightly coupling and sensor fusion based on raw measurements. Modern GPS chipsets, like e.g. the SiRFstarIII used here, offer a feature called user input that can be used to provide external altitude information. This is a relatively easy way to couple GPS and pressure sensor. Therefore measurements have been taken to find out what the benefit of this feature is. Clearly, an improvement in vertical positioning is observed. Additionally, the altimeter improves the accuracy of horizontal position by more than a factor of 2 in an urban canyon environment (Figure 3).

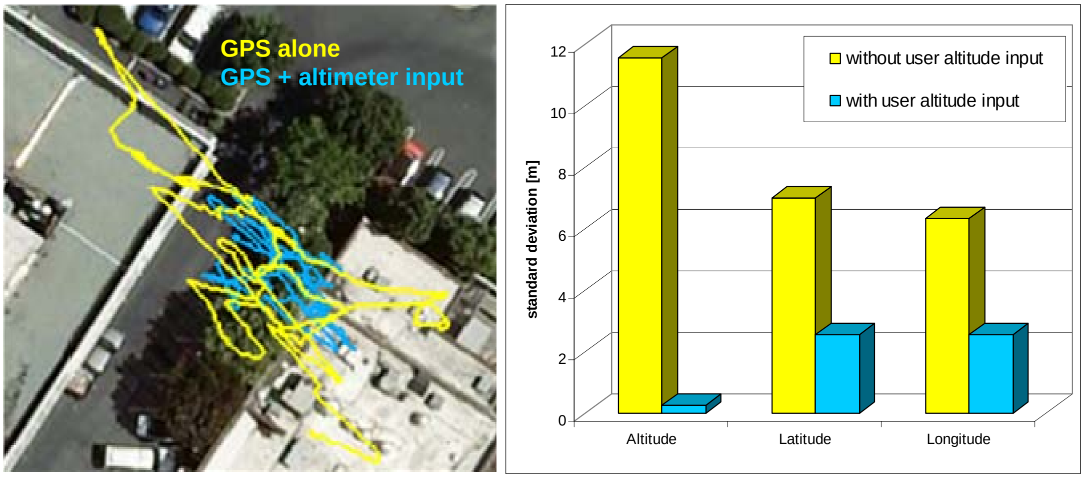

Fig. 3: Positioning error measured in the radio shadow of a 6-story building (true position is fixed in the center of the picture). In comparison with GPS alone (yellow), GPS navigation assisted by the altimeter (blue), shows a significantly better accuracy in this situation, on the vertical and the horizontal axis.

To take advantage of the shown accuracy improvements for the use case of pedestrian navigation a SW application has been developed combining the BMP085 pressure sensor with this altitude user input of a SiRFstarIII chipset. This includes (Figure 4):

- The pressure sensor is used for more precise vertical positioning (altitude) that allows e.g. indoor floor detection.
- The necessary altimeter calibration is done whenever reliable GPS altitude is available. This is implemented using a Kalman Filter.
- Horizontal improvements in urban canyons are achieved with BMP085 altitude input to the SiRFstarIII chipset.

GPS and altimeter complement one another by compensating the other's shortcomings. In combination they provide a more reliable positioning than each standalone system especially indoors and in urban canyons.

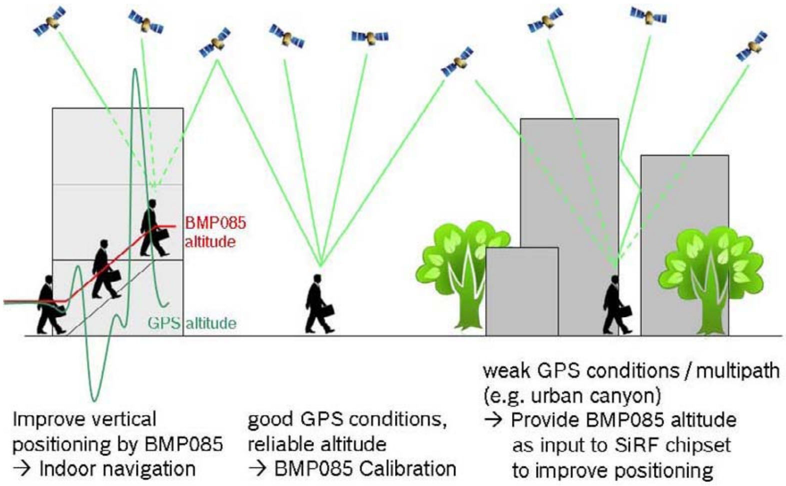

Fig. 4: Principle of dynamic zero compensation. During indoor navigation, the high resolution BMP085 signal replaces the weak, inexact GPS signal (left). During periods of strong reception, the accurate GPS signal calibrates the pressure sensor (middle). In urban canyons, the pressure sensor again replaces the GPS altitude signal, which has become unreliable due to multipath reception.

3. Step counter for 3D dead reckoning inside buildings

An acceleration sensor can be used to count the number of steps the user has covered. The complete path length can be obtained by multiplying this step count with the step length. This method is quite accurate as long as the algorithm is calibrated with the correct step size and this step size remains constant in time.

However, the step length will be reduced if the user climbs a flight of stairs or a ramp, thus significantly degrading the accuracy of the path length. We solved this problem with the BMP085 altimeter. If a stair is detected, the step length is reduced, yielding the correct path length.

4. Floor finder

Changes in altitude are not the only cause for changes in pressure. Pressure may also change due to changes in weather, after opening windows in a room, or due to air conditioning. Although we use a precision MEMS air pressure sensor BMP085 to achieve 0.25m rms resolution, these distortions could correspond to several floors.

Therefore, we implemented a filter that can reliably distinguish between changing the floor and pressure changes due to other effects. The floor finder algorithm internally keeps track of the current altitude. Only when a pressure change due to an altitude change has been detected, the altitude is updated accordingly.

As can be seen in figure 5, the algorithm shows a robust and reliable performance and indicates the correct floor.

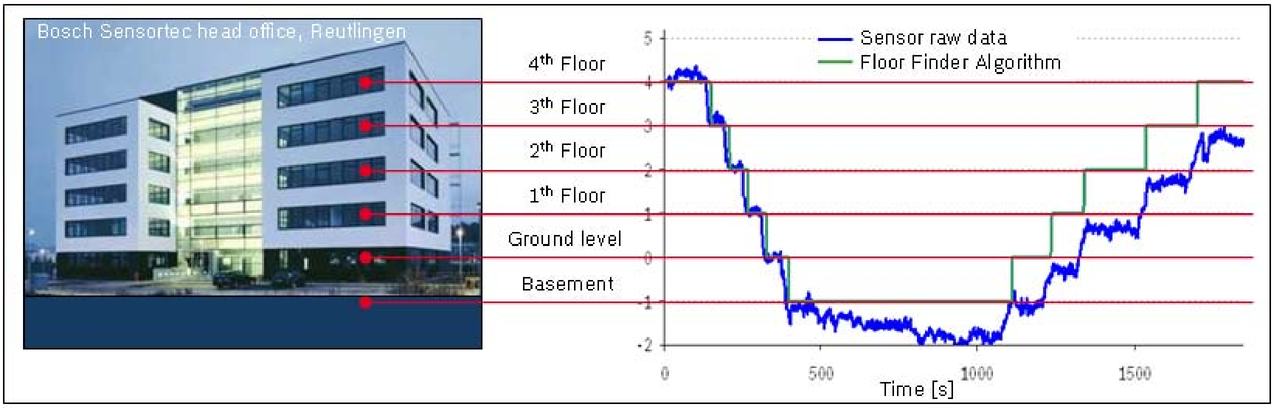

Fig. 5: Accurate floor level sensing, done with an altimeter. The smart algorithm filters out drift from weather changes, noise and wind pressure fluctuations.

5. Conclusion

MEMS sensors and GPS provide excellent synergy to extend navigation capabilities for use cases inside buildings without the need of additional infrastructure.

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